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Effectiveness of a Sound Deterrent in Excluding Gizzard Shad at Lambton TGS Preliminary Laboratory and Field Results

Report No 88-103-K

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ABSTRACT

The effectiveness of sound in eliciting a reponse from gizzard shad was investigated. Preliminary laboratory results suggested that juvenile gizzard shad elicited a negative avoidance response to a sound device at frequencies ranging from 41 to 422 Hz but only when the sound amplitude level was increased. Four "hammer" sound deterrents were placed in front of the Lambton GS intake during the early winter. The effectiveness of these devices in reducing the number of shad entering the intake was not evaluated because of the low number of fish in the proximity of the intake during experimentation. However, preliminary experiments were conducted at the discharge. The hammer elicited a negative response from shad present in the discharge for the different signal frequencies evaluated. Extent of the influence was limited to less than 5 metres. Preliminary results indicated that gizzard shad failed to acclimate to the sound stimulus for a period of at least two hours using a frequency signal of 80 and 500 Hz.

job	file	date	report no.
34-148-592	837.315	November 17, 1988	88-103-K

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EXECUTIVE SUMMARY

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Fish impingement at Ontario Hydro Generating stations has caused operational problems in the form of unit deratings or shutdowns. Unit deratings have been especially significant at Lambton TGS where sixty incidences have occurred over the 1983 and 1984 period alone as a result of gizzard shad (*Dorosoma cepedianum*) impingement. Although these deratings have been frequent, they have not been too costly. Historically, costs arising from impingement have approximated $198,000 (1984 $). As a result, cost-effectiveness is a requirement of strategies developed to reduce impingement. One such strategy has been to exploit the behavioural responses of fish to various stimuli, such as sound, as a potential relatively inexpensive means of handling fish.

Preliminary laboratory and field experiments were conducted on the responses of gizzard shad to different frequencies of sound produced by two sound projectors, the "fishdrone" and the "hammer". In the laboratory juvenile shad responded to frequencies in the range of 41 to 422 Hz. The negative response exhibited by shad was enhanced by increasing the amplitude of the signal. The area of influence appeared to vary with amplitude. Hammer sound deterrents were installed at Lambton's intake. The effectiveness of the hammers in reducing the number of shad entering the intake could not be evaluated due to the low numbers of fish in the proximity of the intake. Preliminary experiments carried out at Lambton's discharge suggested that the signal output from the hammer, (either signal frequency of 80 and 500 Hz, or 110 and 600 Hz), elicited a negative response from adult gizzard shad. Extent of the influence was estimated to be less than 5 metres. Results also suggested that fish failed to acclimate to the signal output from the hammer for a period of at least two hours.

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Effectiveness of a Sound Deterrent in Excluding Gizzard Shad at Lambton TGS Preliminary Laboratory and Field Results

1. INTRODUCTION

Fish impingement at Ontario Hydro Generating stations has caused operational problems in the form of unit deratings or shutdowns. Unit deratings have been especially significant at Lambton TGS where sixty incidences have occurred over the 1983 and 1984 period alone as a result of gizzard shad (*Dorosoma cepedianum*) impingement. Althought these deratings have been frequent, they have not been too costly. Historically, costs arising from impingement have approximated $198,000 (1984 $, OHCTS 1984). As a result, cost-effectiveness is a requirement of strategies developed to reduce impingement. One such strategy has been to exploit the behavioural responses of fish to various stimuli, such as light and sound, as a potential relatively inexpensive means of handling fish.

The use of sound as a behavioural tool for controlling fish movement has recently received considerable attention (Haymes and Patrick, 1986, McKinley and Patrick 1986, OHRD Report No 87-117-K). These studies have shown that a pneumatic popper, which produces a high amplitude, low frequency sound, has proven effective in excluding a species related to gizzard shad; adult alewife (*Alosa pseudoharengus*). The fixed frequency and amplitude of the device, however, has not proven effective in eliciting a negative response in other species such as juvenile coho salmon (*Oncorhynchus kitsutch*) (Patrick 1985). A species specific response to sound, however, is expected since hearing ability among fishes has been shown to be dissimilar (Tavolga 1971). By knowing how key species respond to various frequencies and amplitudes of sound, an effective sound barrier could be developed.

Two recently developed alternatives to a pneumatic popper, the "fishdrone" and "hammer", have considerably advanced research in the use of sound for the management of fish stocks. The flexibility of the fishdrone in producing a wide variety of frequencies (20-1000 Hz) has compensated for the species specific response to sound. In preliminary experiments at Lambton TGS, gizzard shad were observed to show a negative response to a fishdrone at a

fundamental frequency of approximately 153 Hz (OHRDR CB86-4-K). The other sound deterrent, the hammer, is a mass spring impact device which produces a low frequency, high amplitude sound (>10 kPa 1 m from the source). This device produces an impulsive type sound (short rise, exponential decay) which we believe is important in eliciting a fish avoidance response. The frequency output of the hammer can be altered easily with minimal alteration to the device.

The overall objective of this study was to determine the effectiveness of a sound stimulus in reducing the capture of gizzard shad at Lambton's intake. The study consisted of two phases. The initial phase, conducted in the laboratory, sought to determine the roles of both sound pressure level and frequency in eliciting a response from shad. The second phase, which was done in the vicinity of the station's intake and discharge, evaluated the response of shad to sound under field conditions. These studies were conducted in the winter of 1986-87.

2. MATERIALS AND METHOD

2.1. Phase 1 Laboratory Study - Preliminary Results

The objective of this phase was to determine the roles of frequency and sound pressure level which elicited the greatest response in juvenile gizzard shad. Experiments were conducted in a semi-anechoic square tank (Figure 1). A concrete block wall was installed along the inside perimeter of the tank to minimize sound reverberations. The tank was equally divided into two distinct sections, each 1.5 m deep. This allowed an experimental and a control test to be conducted concurrently (ie. a paired experimental design). Each section was further subdivided into eight observational zones (3.5 m x 3.5 m). The effectiveness of the fishdrone was determined by the difference in the number of shad in each zone relative to that observed under control conditions. There were sixteen zones in the entire tank (8 experimental, 8 control). Water temperature during these tests was below 10°C. There was no current in the tank.

The fishdrone was positioned in one outside corner of the experimental half of the tank. In all remaining outside corners, including the control half of the tank, "dummy fishdrones" were positioned so as to remove any visual reference to the real fishdrone.

The responses of juvenile gizzard shad to six frequencies, generated by the fishdrone, were determined. These were 41.1, 84.8, 117, 150.1, 248 and 422 Hz. Each frequency was evaluated at two amplitude levels, which were estimated to be approximately 0.1 and 1.0 kPa. Because there was difficulty collecting large numbers of fish only one test was conducted for each frequency and amplitude combination. Fifteen to twenty fish were used in each experiment. Sound production from the fishdrone was in burst form, three seconds on, one second off. This particular mode of production has been found to be effective in repelling fish in preliminary field trials at Lambton TGS (OHRD Report CB86-4-K). A detailed description of the fishdrone is given by McKinley and Patrick 1986.

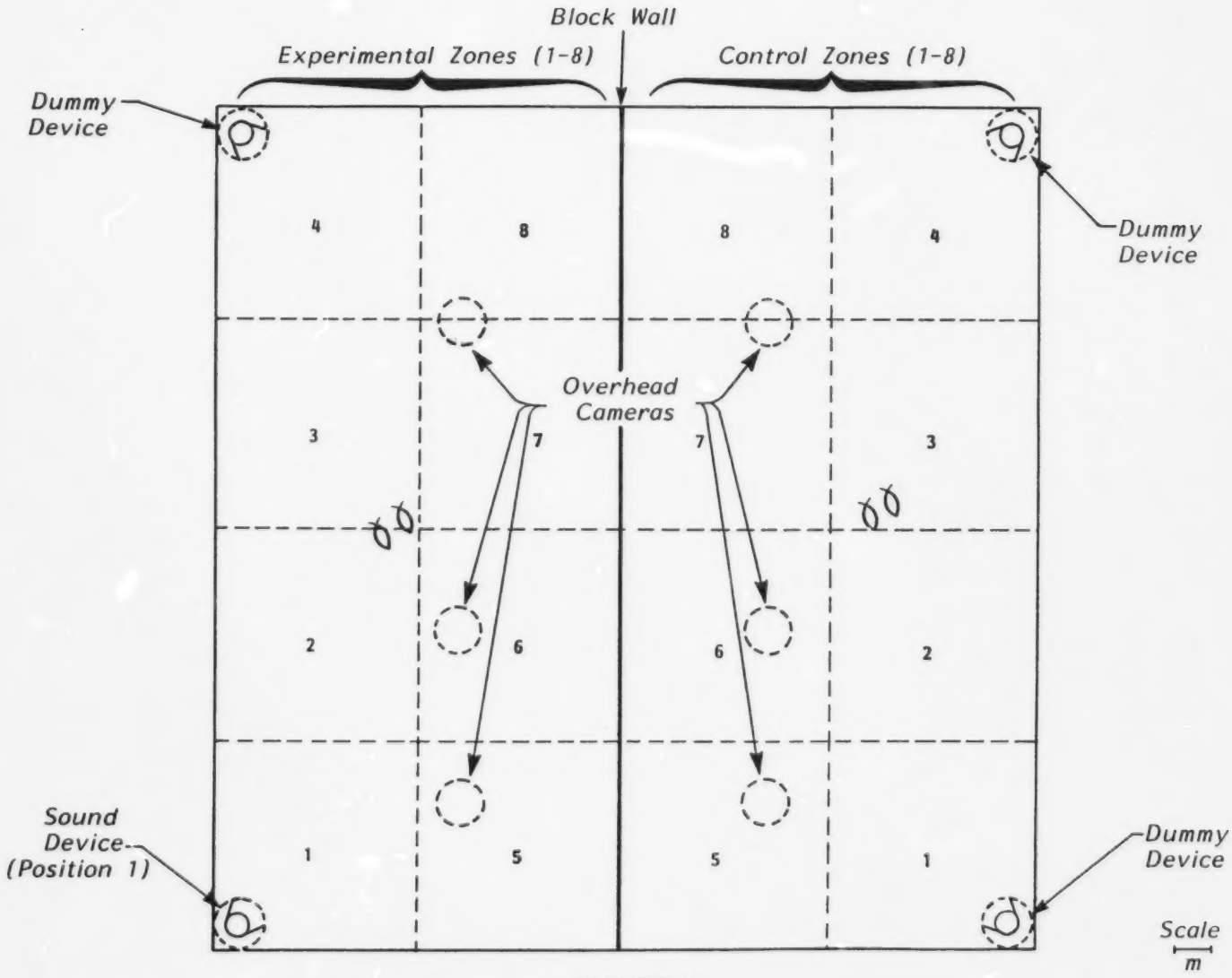

FIGURE 1
EXPERIMENTAL TEST FACILITY
(15.5m L, 15.5m W, 1.5m D)
(Eight Control and Experimental Zones)

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Experiments were five minutes in length. The distribution of shad relative to the fishdrone was noted at thirty, ten second intervals. It was felt that if fish responded it would be within this time period. These experimental results were compared to the distribution and behaviour of fish in each section of the tank with the fishdrone off. All data were obtained visually and by the use of closed circuit cameras positioned both above and below the water.

Since few experiments were conducted (because of fish availability problems), these laboratory results should be considered preliminary.

2.2. Phase 2 Field Study - Preliminary Results

Experiments to determine the responses of adult shad to two different frequency signals emitted from the hammer sound deterrent, were conducted in the vicinity of the station's intake and discharge. The hammer, as opposed to the fishdrone, was used in the field because this device produced more of an impulsive signal of higher amplitude. Previous investigations have emphasized the importance of a high and impulsive sound stimulus in eliciting a behavioural response in fish (McKinley and Patrick 1986). For a detailed description of the hammer device consult McKinley and Patrick 1986.

Four hammers were positioned at the mouth of the intake and aimed upstream, downstream and approximately perpendicular to the shoreline (Figure 2a). This hammer configuration provided the intake with an acoustical energy coverage expected to be approximately 10 kPa at a distance of several metres from the source. Shad activity in the area with the hammers on (experimental) and off (control) was monitored using sonar. In addition, the impingement records for shad during the experimental and control periods, were used to supplement the sonar data.

The response of shad to the hammer was also recorded at the discharge. This was because sufficient numbers of fish were not observed at the intake over the 4 week sampling period. Testing at the intake, therefore, was suspended. At the discharge, the approximate distribution of shad in front of the hammer and at four consecutive 2.4 m intervals was visually observed. Each of these five observational zones encompassed a volume of approximately 2.4 m wide, 2.4 m long, and 1.5 m deep (Figure 2b). The number of shad in each of these zones was expressed as a per cent of the total number of fish observed in all zones. Effectiveness of the hammer was determined by comparing the number of shad in each zone during control (hammer off) and experimental (hammer on) periods. A one-half hour "rest period" separated the termination of an experimental period and the start of the next control. The reaction of shad was noted every minute for both short (20 minute) and long term (2 hour) experimental tests. The experimental protocol was conducted using different end plates which produced specific frequencies (fundamental of 80 and 500 Hz, 110 and 600 Hz).

3. RESULTS AND DISCUSSION

Preliminary laboratory results indicated that juvenile gizzard shad did not show a marked avoidance response in the four zones closest to the operating fishdrone at low sound amplitude levels (Figures 3a and 3b). However, with an increase in amplitude (to 1.0 kPa) the avoidance response appeared to increase for most frequencies (except 84.8 and especially

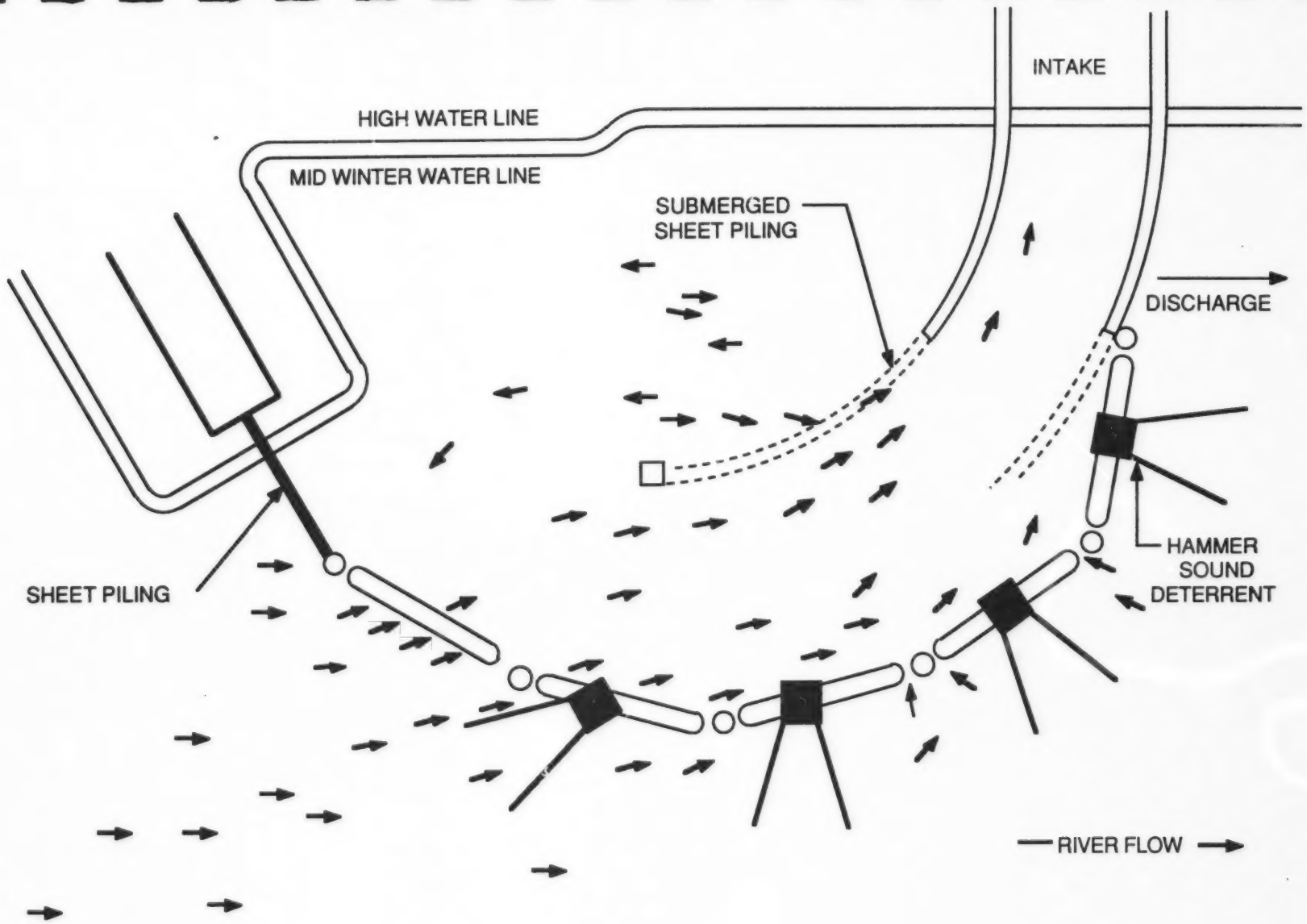

FIGURE 2a

LOCATION OF HAMMER SOUND DETERRENTS - LAMBTON TGS INTAKE
(ARROWS DEPICT WATER MOVEMENT)

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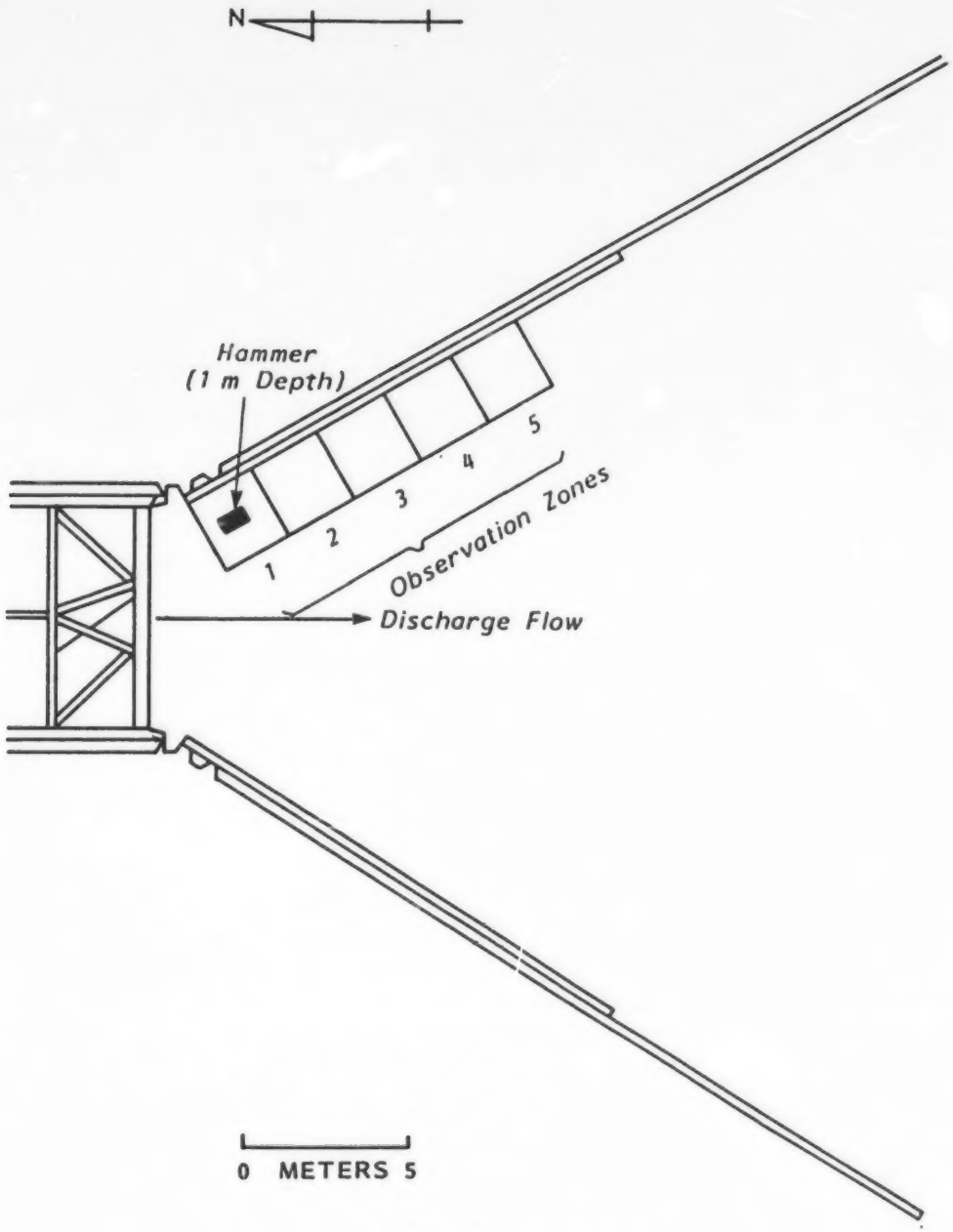

FIGURE 2b

SCHEMATIC REPRESENTATION OF LAMBTON TGS DISCHARGE SHOWING THE POSITIONING OF THE HAMMER AND THE FIVE OBSERVATION ZONES (2.4 mL X 2.4 mW X 1.5 mD).

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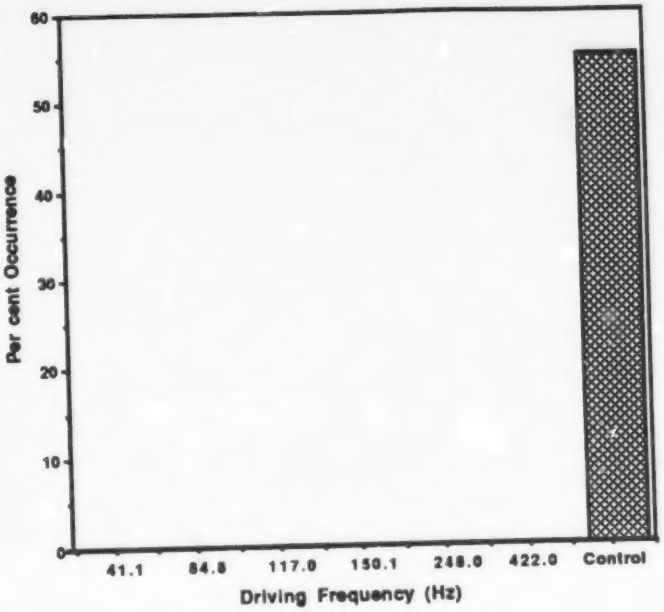

FIGURE 3a

PER CENT OCCURRENCE OF JUVENILE SHAD OBSERVED IN TWO ZONES (7.0m x 3.5m) OF THE TANK CLOSEST TO THE FISHDRONE AT VARIOUS FREQUENCIES UNDER LOW AMPLITUDE.

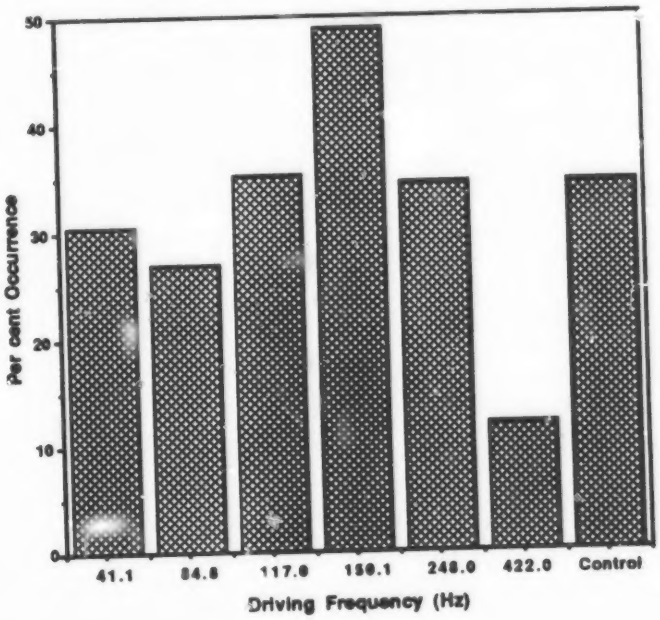

FIGURE 3b

PER CENT OCCURRENCE OF JUVENILE SHAD OBSERVED IN FOUR ZONES (7.0m x 7.0m) OF THE TANK CLOSEST TO THE FISHDRONE AT VARIOUS FREQUENCIES UNDER LOW AMPLITUDE.

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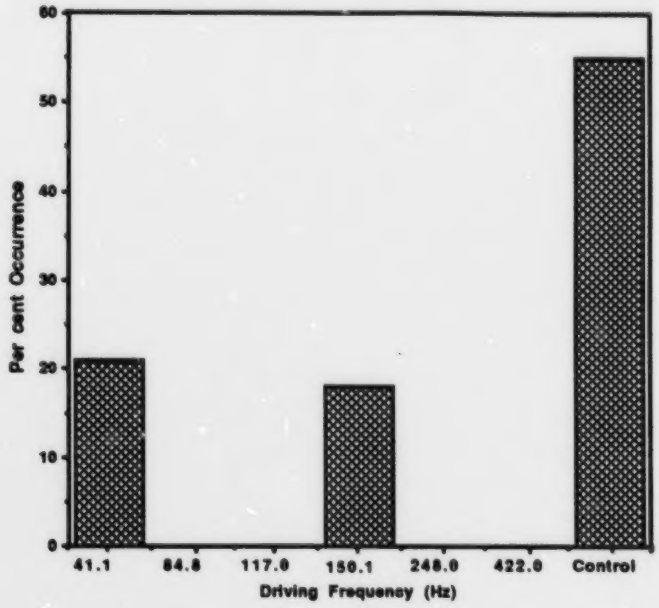

FIGURE 4a

PER CENT OCCURRENCE OF JUVENILE SHAD OBSERVED IN TWO ZONES (3.5m x 7.0m) OF THE TANK CLOSEST TO THE FISHDRONE AT VARIOUS FREQUENCIES UNDER HIGH AMPLITUDE.

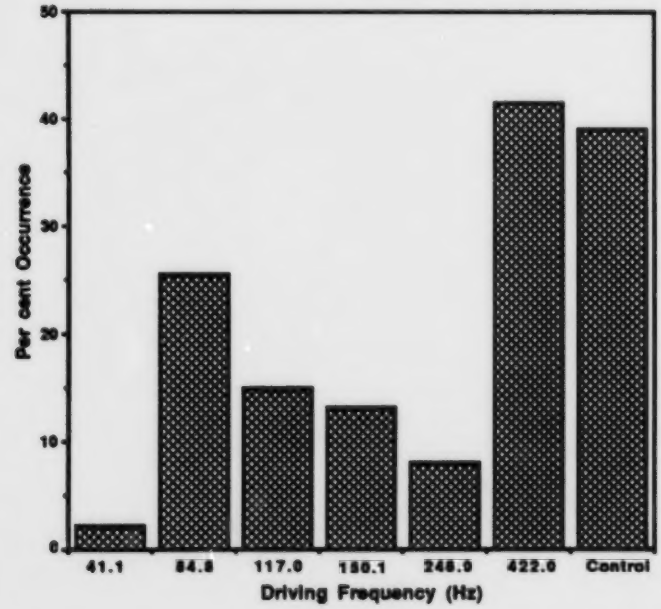

FIGURE 4b

PER CENT OCCURRENCE OF JUVENILE SHAD OBSERVED IN FOUR ZONES (7.0m x 7.0m) OF THE TANK CLOSEST TO THE FISHDRONE AT VARIOUS FREQUENCIES UNDER HIGH AMPLITUDE.

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422 Hz) to approximately 7.0 metres or half of the experimental tank (Figure 4b). The reaction by shad to those frequencies which elicited a response was always directional and immediate. The majority of these fish remained outside the fishdrone's area of influence for the duration of the experiment (5 min, greater than 5.0 m distance from the fishdrone). Most fish were present in zones 7 and 8 (Figure 1) when the fishdrone was operating (in zone 1). Exceptions were the 84.8 and 422 Hz levels where the response was not as strong and fewer than a third of the shad responded (Figures 4a and 4 b). The estimated area of influence based on these laboratory results (most frequencies) appeared similar to that observed previously at Lambton TGS using the fishdrone at a similar amplitude, but at a frequency of 153 Hz (OHRD Report CB86-4-K).

Hammers, positioned at the intake, were operated "off" and "on" for a period of approximately 30 days. The effectiveness of the hammers in reducing the number of shad entering the intake was not evaluated due to the low number of fish in the proximity of the intake. During this period, impingement of gizzard shad was uncharacteristically low. Historically (1983-85), shad impingement during January averaged approximately 55,000 individuals. During our testing period, shad impingement represented less than 8 per cent of the historic average (OHCTS 1988). Reasons for this low impingement rate are not known. One hammer was subsequently moved to the discharge area where the response of shad to two different frequency signals could be evaluated.

A negative response was elicited from gizzard shad using a hammer which produced estimated fundamental frequencies of 110 and 600 Hz. Extent of the influence, however, was limited to less than 5 metres (Figure 5). The majority of shad also did not return to the vacated area during a two hour experimental period (Figure 6). These preliminary results suggest that gizzard shad did not acclimate to the projected sound stimulus. Similar avoidance results were obtained using a hammer which produced estimated fundamental frequencies of 80 and 500 Hz (Figure 7).

The apparently greater negative response demonstrated by shad to the signals produced by the hammer than from similar frequencies produced using the fishdrone at 84.8, 422 Hz perhaps further underscores the importance of amplitude and delivery of the signal (time history). The amplitude of the signal produced using the hammer was estimated to be a factor of ten higher than that from the fishdrone. The delivery mode from the hammer was also more impulsive than the signal output from the fishdrone.

4. SUMMARY

(1) Juvenile gizzard shad in an experimental tank responded to frequencies in the range of 41 to 422 Hz. The negative response exhibited by shad was enhanced by increasing the amplitude of the signal. The area of influence appeared to vary with amplitude.

(2) Hammer sound deterrents were installed at Lambton's intake. The effectiveness of the hammers in reducing the number of shad entering the intake could not be evaluated due to the low numbers of fish in the proximity of the intake.

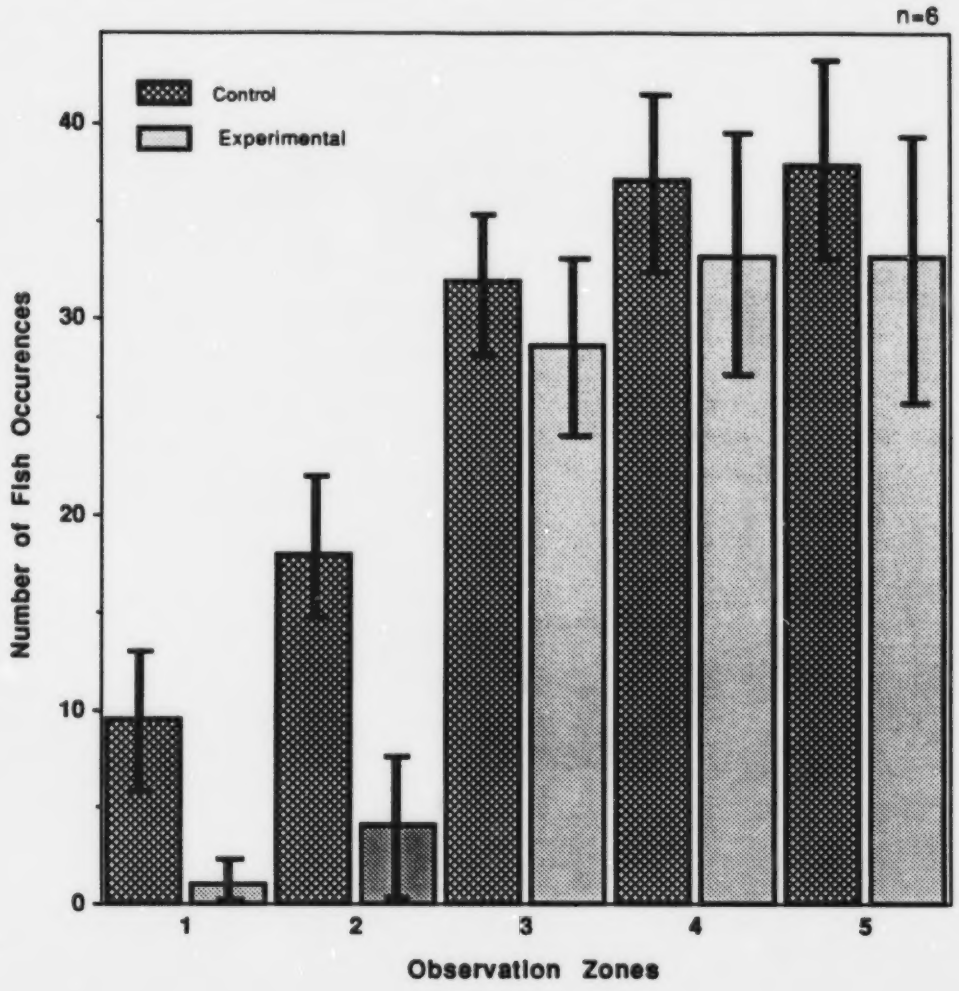

FIGURE 5

RESPONSE OF ADULT GIZZARD SHAD TO A HAMMER WITH A FREQUENCY SIGNAL OF 110 AND 600 Hz AFTER A TWENTY MINUTE DURATION. DATA DEPICTS THE AVERAGE NUMBER OF SHAD (±S.D.) AMONG 5 OBSERVATIONAL ZONES. EACH ZONE INCREASED CONSECUTIVELY BY 2.4 m FROM THE HAMMER.

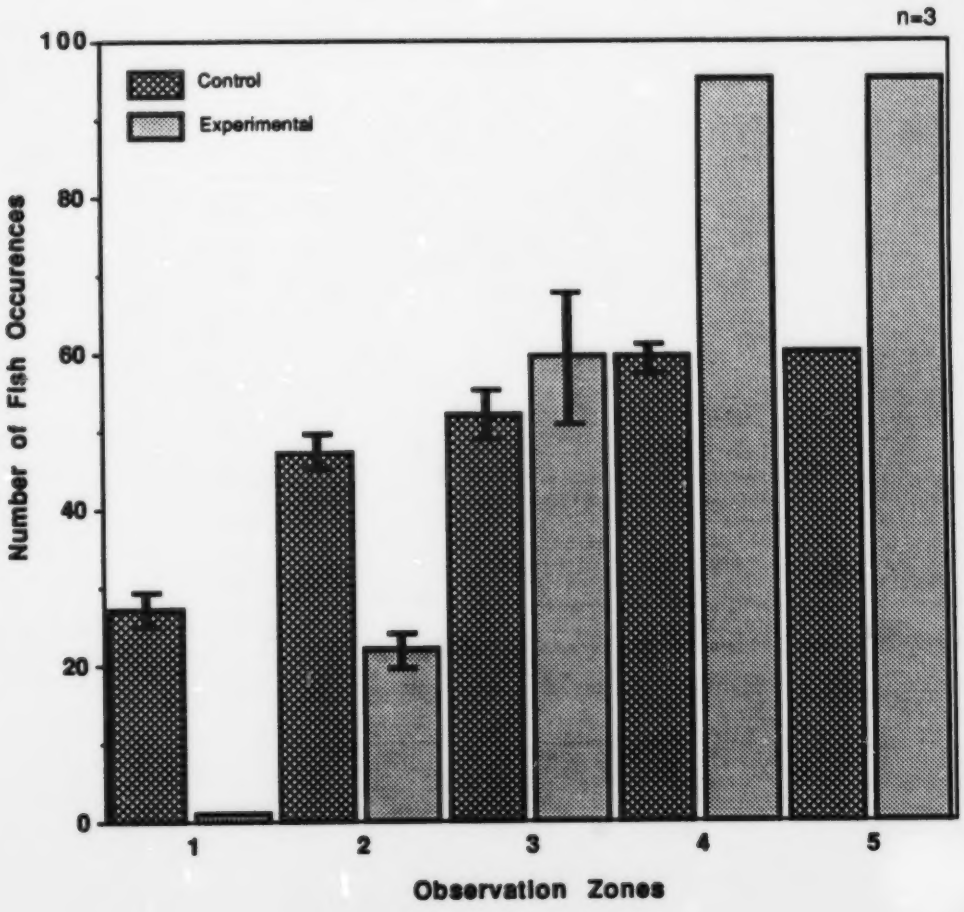

FIGURE 6

RESPONSE OF ADULT GIZZARD SHAD TO A HAMMER WITH A FREQUENCY SIGNAL OF 110 AND 600 Hz AFTER A TWO HOUR DURATION. DATA DEPICTS THE AVERAGE NUMBER OF SHAD (± S.D.) AMONG 5 OBSERVATIONAL ZONES. EACH ZONE INCREASED CONSECUTIVELY BY 2.4 m FROM THE HAMMER.

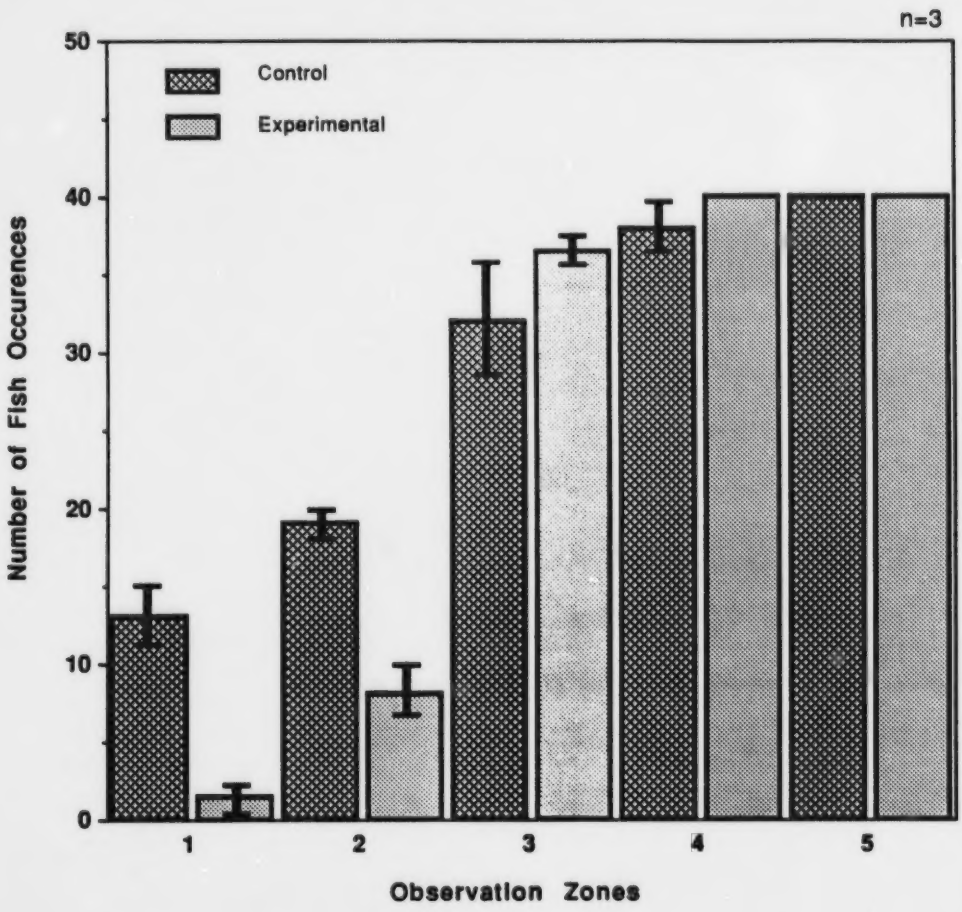

FIGURE 7

RESPONSE OF ADULT GIZZARD SHAD TO A HAMMER WITH A FREQUENCY SIGNAL OF 80 AND 500 Hz AFTER A TWENTY MINUTE DURATION. DATA DEPICTS THE AVERAGE NUMBER OF SHAD (± S.D.) AMONG 5 OBSERVATIONAL ZONES. EACH ZONE INCREASED CONSECUTIVELY BY 2.4 m FROM THE HAMMER.

(3) Preliminary experiments carried out at Lambton's discharge suggested that the signal output from the hammer, (either signal frequency of 80 and 500 Hz, or 110 and 600 Hz), elicited a negative response from adult gizzard shad. Extent of the influence was estimated to be less than 5 metres.

(4) Preliminary tests conducted at the station's discharge also suggested that fish failed to acclimate to the signal output from the hammer for a period of at least two hours.

ACKNOWLEDGEMENTS

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REFERENCES

(1) Haymes, G.T. and Patrick, P.H. 1986. Exclusion of adult alewife, *Alosa pseudoharengus*, using low frequency sound for application at water intakes. Can. J. Fish Aquat. Sci. 43:855-862.

(2) McKinley, R.S. and Patrick, P.H. 1986. Fish protection: sonic deterrents. Empire State Electric Energy Research Corporation, EP 85-14.

(3) Ontario Hydro Central Thermal Services, 1984. CTS-NA27-07015.01-9. Economic evaluation of the 1983-1984 acute fish impingement events at Lambton TGS. M.A. Cross and P.M. Wiancko.

(4) Ontario Hydro Research Division Report No 87-117-K. Effectiveness of a sonic device in repelling adult alewife at the Pickering Nuclear Generation Station. R.S. McKinley and P.H. Patrick.

(5) Ontario Hydro Research Division Report No CB86-4-K. Initial responses of adult gizzard shad to sound and strobe lights. R.S. McKinley and P.H. Patrick.

(3) Ontario Hydro Central Thermal Services, 1984. CTS-NA27-07015.01-9. Economic evaluation of the 1983-1984 acute fish impingement events at Lambton TGS. M.A. Cross and P.M. Wiancko.

(6) Ontario Hydro Central Thermal Services, 1987. CTS-07015-21. Fish Impingement Results from Ontario Hydro Thermal Generating Stations. R. Kozopas.

(7) Ontario Hydro Central Thermal Services, 1988. Draft Data Impingement Statistics at Lambton 1983-6. R. Kozopas.

(8) Patrick, P.H. - 1985. Behavioural systems to guide or divert fish at hydro-electric facilities. Report prepared for the Canadian Electrical Association.

(9) Tavolga, W.N. 1971. Sound production and detection. pp. 135-205. In. W.S. Hoar and D.J. Randall (Eds). Fish physiology, Vol. 5. Academic Press, New York.